INSTALLING A HYDROACOUSTIC STATION AT THE CROZET ISLANDS

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ABSTRACT

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) International Monitoring System (IMS) includes a network of eleven hydroacoustic stations for monitoring the Earth’s oceans, six of which are hydrophone stations, while the remaining six are on-land seismometer-based stations. The efficient propagation of acoustic energy through the Sound Fixing and Ranging (SOFAR) channel makes it possible to effectively monitor large ocean areas with a small number of stations. Ten of the eleven stations in this network have been installed and certified. The remaining station is designated HA04 and is located in the Crozet archipelago, a French territory in the southwestern Indian Ocean. While the location of this site provides unique monitoring capabilities for the IMS, the site presents significant design and installation challenges because of the environmental conditions in the area. This paper addresses some of the main challenges associated with the establishment of HA04 that have been identified based upon the experiences of the prior installation and of a more recent design and feasibility study. These results will be used to move forward with the design and installation of the station.

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14. ABSTRACT

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) International Monitoring System (IMS) includes a network of eleven hydroacoustic stations for monitoring the Earth?s oceans, six of which are hydrophone stations, while the remaining six are on-land seismometer-based stations. The efficient propagation of acoustic energy through the Sound Fixing and Ranging (SOFAR) channel makes it possible to effectively monitor large ocean areas with a small number of stations. Ten of the eleven stations in this network have been installed and certified. The remaining station is designated HA04 and is located in the Crozet archipelago, a French territory in the southwestern Indian Ocean. While the location of this site provides unique monitoring capabilities for the IMS, the site presents significant design and installation challenges because of the environmental conditions in the area. This paper addresses some of the main challenges associated with the establishment of HA04 that have been identified based upon the experiences of the prior installation and of a more recent design and feasibility study. These results will be used to move forward with the design and installation of the station.

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OBJECTIVES

The CTBT IMS has the objective of providing global monitoring to detect nuclear explosions in any environment. The eleven stations comprising the hydroacoustic network principally look for explosions in the water column of the Earth's oceans and above the ocean surface. The efficient transmission of acoustic energy through the SOFAR channel allows a small number of stations to effectively cover most of the world's oceans. Six of the IMS stations are hydrophone stations, where moored hydrophones float in the SOFAR channel suspended above the seafloor on vertical risers suspended by submerged buoys. Such stations require major installation efforts because of the remote sites where they are deployed and the challenges of deep undersea cable laying operations. Five of the six hydrophone stations in the IMS have been certified and four are currently part of IDC operations. One of the two stations not in operation is HA03 in Juan Fernandez, Chile, which is awaiting repair after having been destroyed by a Tsunami in 2010. The other station, designated HA04 and located on Ile de la Possession in the Crozet archipelago in the southwestern Indian Ocean, will be re-established after having suffered damages during repair and successive anchoring incidents. The re-establishment requires removal of the previous equipment and reinstallation of an entirely new shore component, trunk cables and hydrophone triplets. Given the particularly harsh conditions that prevail in the area, the successful installation of a sustainable certified International Monitoring System hydrophone station at Crozet requires careful consideration of the particular environment in the area.

RESEARCH ACCOMPLISHED

The Crozet Islands are a sub-Antarctic archipelago of small islands that are part of the French Southern and Antarctic Lands (Terres Australes et Antarctiques Françaises, labeled TAAF). The largest island in the group is the 150 km^2 Possession Island located at 46°24′ S, 51°46′ E. The Island is of volcanic origin and sits atop the Del Cano Plateau, which has an average water depth of 2,000 m. The island is uninhabited except for the staff of the Alfred Faure scientific research station, which can provide local support for the IMS station. There is no harbor or airstrip, but there is a small dock facility on the Baie du Marin to accommodate cargo deliveries by lighter vessels (Figure 1). The CTBTO Provisional Technical Secretariat (PTS) and France worked together on the first installation of HA04 since 1999. Similarly to other IMS hydrophone stations situated on islands, two triplets were deployed in 2000, one approximately 40 km North of the island and one approximately 50 km South of it. By February 2006, the station ceased permanently to send data due to technical issues and ship-anchoring incidents that damaged both the North and the South trunk cables in shallow waters. Nevertheless, much useful data on ambient acoustic noise at Crozet, as well as valuable experience on performing installation operations around Crozet, was accumulated through this previous work. It should be noted, that HA04 was the first cabled installation ever attempted at these latitudes.

Figure 1. Photograph showing Alfred Faure base and the only limited available shore landing facility on Ile de la Possession. Part of the colony of penguins which live on the island can be clearly seen.

A hydroacoustic station at Crozet in the Southwestern Indian Ocean, at a latitude south of the Cape of Good Hope, provides important contributions to the IMS monitoring capabilities. First, it increases the azimuthal coverage for events in the Indian Ocean especially between Africa and India compared to that offered by the other IMS hydroacoustic stations in the Indian Ocean at the British Indian Ocean Territories (BIOT) and Cape Leeuwin, Australia. This provides an improvement in location capability in that region. Secondly, its southerly location provides additional monitoring capability into parts of the South Atlantic, as well as improved location capabilities in that area, since the only Atlantic hydrophone station is HA10 on Ascension Island. Third, the location is uniquely placed to give the IMS coverage into the Madagascar Strait, which is not afforded by other locations. Finally, the station location is relatively close to the Antarctic convergence zone and will improve detectability of sources south of the convergence zone. Figure 2 shows the improvements in event detection capability when the IMS includes a station at Crozet Island. However, the location at the high southern latitudes presents multiple challenges. These challenges and their implications on the work to be carried out are discussed below.

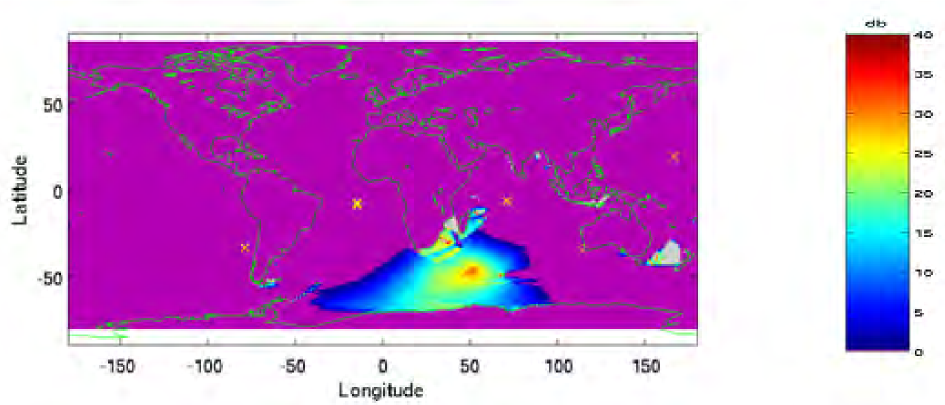


Figure 2. The figure above shows the improvement in hydroacoustic network signal-to-noise ratio (SNR) detectability for a one kiloton surface explosion when the Crozet Is. station is added to the network. Purple indicates areas where the SNR is essentially unchanged when Crozet is added. Note that the grey regions are where there is no detectability without the Crozet Is. station. An “x” is a station location.

The first challenge concerns the selection of the appropriate hydrophone depths. In principle, placing the hydrophones near the axis of the SOFAR channel would give the best performance. The depth of the SOFAR channel axis depends primarily on the temperature in the water column and the hydrostatic pressure. Figure 3 shows the locations of IMS hydroacoustic stations in the Indian Ocean and the annual average depth of the SOFAR channel axis. At Crozet the SOFAR channel effectively extends from near the sea surface down to approximately 700 m and its axis varies significantly depending on the season and somewhat depending on location. The sound-speed gradient is less strong and the SOFAR channel is less well defined in this region compared to other latitudes. However, at the shallow depths at which the channel axis is at Crozet, the disturbance from wave action noise and especially currents could be substantial.

Figure 4 shows noise models for the hydroacoustic stations, derived from long-term averages of the available data. The figure shows that the northern triplet at Crozet Island proved to be the quietest site in the Indian Ocean, while the southern site proved to be the second-noisiest. Further analysis of the characteristics of the noise on timescales of hours, confirm that the noise at the south triplet of the Crozet station is substantially higher than the noise at the north triplet.

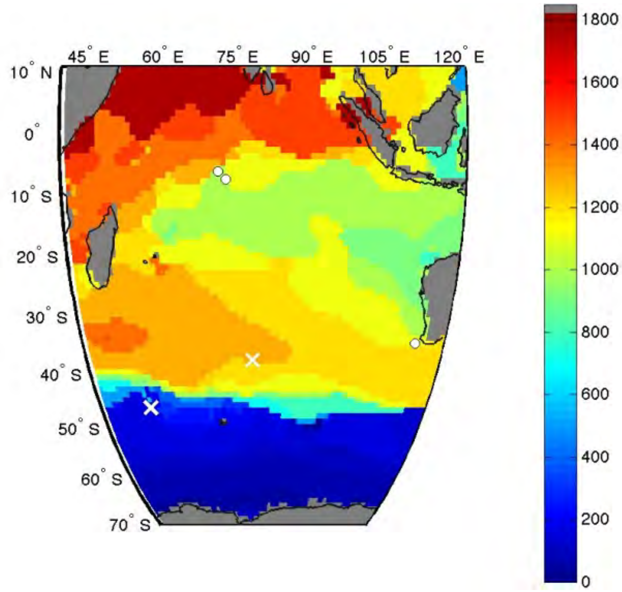


Figure 3. Map of the Indian Ocean from (Mallin, 2012), showing HA01 Cape Leeuwin (rightmost white circle), HA08 BIOT-Diego Garcia (top white circles) and the Crozet archipelago (lower left cross). The colorscale shows the annual averaged depth of the SOFAR channel axis (in m).

Two independent analyses of the noise at HA04 using available data, carried out by CEA (Piserchia et al., 2003) and by CTBTO IDC and IMS in 2012, suggest that currents could be responsible for the high noise level at the South site. Bursts of high noise spectral levels, which last for hours at a time and appear to be related to the tidal cycles, are found consistently in the South triplet data around 10 Hz. Those levels can be up to 50 dB higher than the levels at the North triplet. The North hydrophones were at a depth between 281 m and 290 m, and the South hydrophones were at a depth between 310 m and 350 m. The explanation being considered as the most plausible one is that these noise bursts are caused by strong tide-related sub-surface currents flowing past the hydrophones. Current induced pseudo-noise was first discussed in detail in a journal paper by (Strasberg, 1979). Peaks most likely associated with cable strumming are also visible in the lower part of the noise spectrum in these cases. Besides causing high levels of noise, such currents represent a potential danger to the long-term sustainability of the system, since they may expose the hydrophone risers and moorings to excessive mechanical stresses in the long run. In order to mitigate these risks, the hydrophones need to be placed at locations where the currents do not present any concern. For this reason, a study of the surface and sub-surface currents in the likely deployment area will be undertaken. The study will be performed using state-of-the-art three-dimensional (3-D) ocean modelling tools, and it will provide information which will be crucial for designating hydrophone deployment locations and for the planning of cable deployment operations. As part of this effort, historical ocean, current, sea state and meteorological data as well as available bathymetric and other data will be collected and compiled in a report which will provide a comprehensive picture of the local environment.

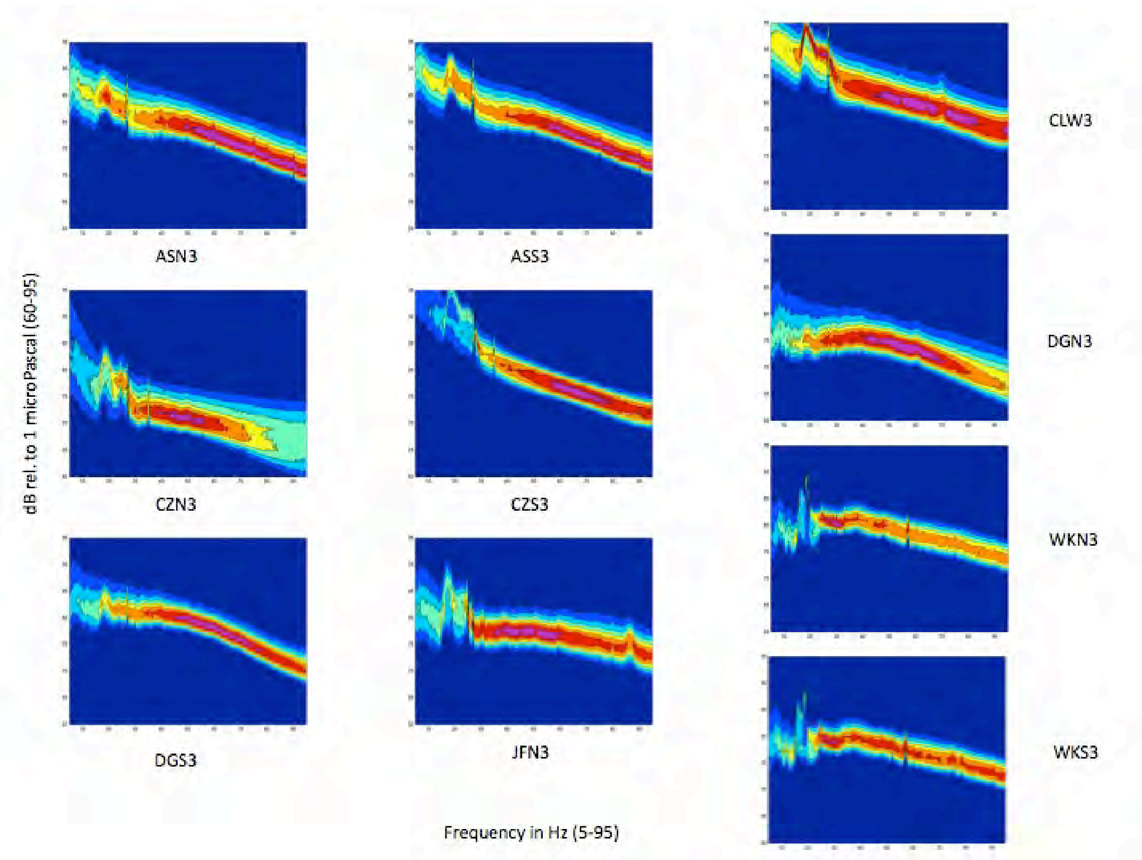


Figure 4. Noise models based on power spectral density (PSD) as a function of frequency for the third sensor in the triplet for the full IMS hydroacoustic network . The naming convention is: AS, CZ, DG, JF, CL, WK for Ascension Is., Crozet Is., Diego Garcia, Juan Fernandez, Cape Leeuwin, Wake Is., respectively. N, S, and W refer to the north arm, south arm, or only arm respectively. The models were constructed using most of the continuous data recorded by all stations from inception through 2009. In the case of Crozet, the models are based on 71% (for the north arm) and 78% (for the south arm) of all data recorded (5000-6000 hours of continuous data). Note that CZN3 and CZS3 models differ by more than any other station arms and that CZN3 has the lowest average noise (and highest variability) of the IMS stations while CZS3 is one of the higher noise stations. Noise model differences between individual sensors forming a triplet proved to be minimal, as one would expect.

When the SOFAR channel axis is sufficiently deep, the amplitude of the low-order acoustic modes is maximal at this depth and hydrophones located near this axis will be most sensitive to the long-range signals of interest for monitoring purposes. In the case of Crozet, where the SOFAR channel is near the surface, the SOFAR channel axis may no longer be the depth of maximum amplitude for low-order modes.

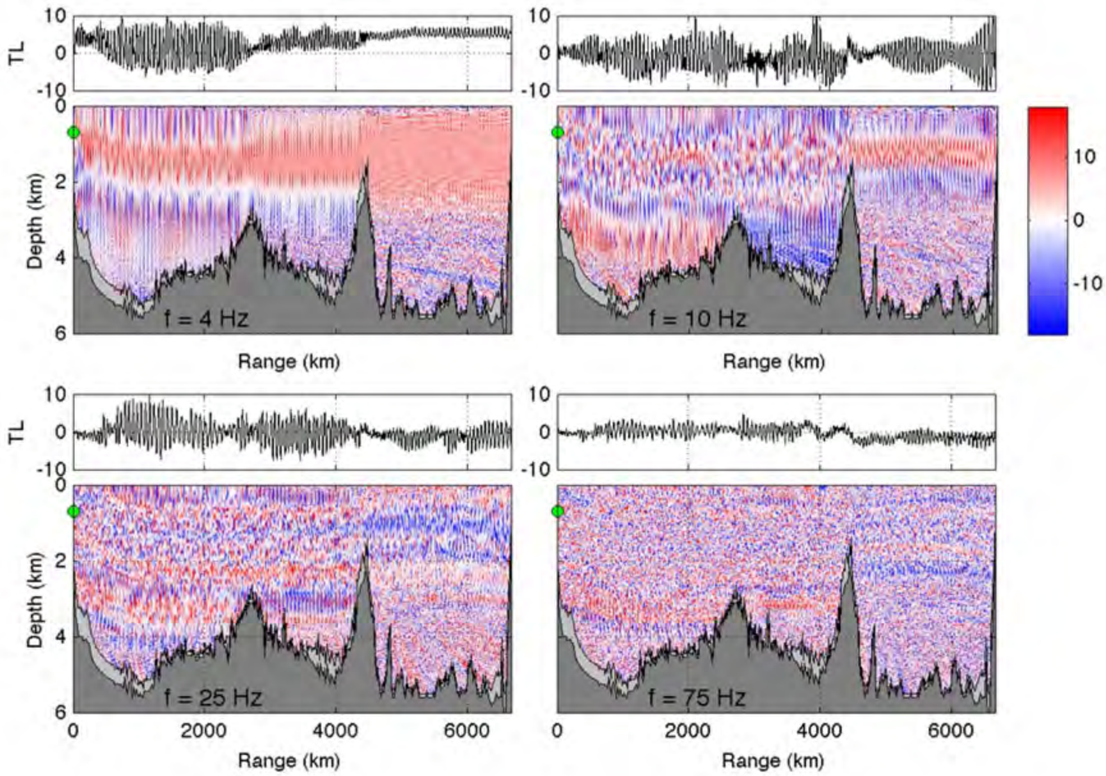


Figure 5. Difference between transmission loss, TL (dB), for a hydrophone at 200 m depth (i.e., at the depth of the SOFAR channel axis at HA04), compared to a hydrophone at 700 m depth, for four different frequencies. The green circles represent the 700 m deep hydrophone. Range 0 km corresponds to the HA04 location. The line-plots show the average TL within the first km depth as a function of range. A positive difference implies an improved reception, whereas a negative difference implies a worse reception. [Figure and caption material from (Mallin, 2012)]

Figure 5 shows the results of a first analysis of transmission loss for the indicated signal path to a potential hydrophone site at Crozet (Mallin, 2012). The analysis shows that the zone of minimum transmission loss is somewhat deeper than the SOFAR channel axis. The depth of the minimum transmission loss varies by frequency and also by season. Taking these variations into account, the optimal depth for the hydrophones deployed in the area is between 500 m and 600 m.

However, the strong sub-surface currents, which could subject the vertical moorings to excessive mechanical stress over the long term and the hydrophones to flow-induced noise, may require that some hydrophones and their respective floats be placed even deeper. Placing the hydrophones further away from the optimal depths has implications on the acoustic performance of the system, and therefore one needs also to bear in mind the tradeoffs associated with an increased transmission loss in this case. Another aspect which is likely to complicate the decisions regarding the South triplet is that most acoustic rays reaching the station from the South are likely to travel through large areas where the sound speed profile is an upward refracting arctic profile (represented by the deeper blue areas in Figure 3). These issues will be addressed in an upcoming high-fidelity long range (at ocean basin scales) propagation modelling effort, through which the acoustic performance of the station as a function of hydrophone location and depth will be carefully evaluated.

Despite Crozet's remoteness, ships do visit and anchor offshore. This includes the visiting resupply vessels and roughly monthly visits by a patrol vessel. Crozet also provides one of the few somewhat sheltered anchorages available for longliner fishing vessels. Possession Island has a designated anchorage zone near Baie du Marin, which is the only site where the cable for the shore recording facility can be landed. Anchorage represents the biggest hazard for the underwater cables and for the entire hydroacoustic station. The segment of the cable nearest to shore

is generally surrounded by an iron split-pipe conduit to protect the cable from near shore hazards. Nevertheless, the anchors of some larger ships can damage the cable regardless of the split-pipe protection.
While there is a designated anchorage and maps showing areas where anchoring is not permitted are available to mariners, this is not a complete solution. In stormy conditions, anchored ships can drift, potentially dragging the anchor into the cable route. Under such conditions, the ship's master will give priority to the safety of the ship and personnel on board, so the best approach, beyond proper cable armoring and protection, is the routing of the cable as far as possible from the anchorage zones or from zones where anchors could be dragged into the cable. This will require the use of improved techniques of controlling and guiding the cable as it falls to depth. Such techniques were not readily available at the time of the initial installation effort at Crozet, but they are available now.

The location of Crozet exposes it to a nearly unlimited fetch contributing to frequent strong storms and high sea states even during the austral summer and to very rapidly changing conditions. This has significant consequences for station design and deployment. During the earlier installation efforts, winds were found to frequently exceed 35 knots. In general, strong winds can appear in the area abruptly and reach speeds of 80 knots in less than a couple of hours, and sometimes exceed 140 knots. The resulting sea states are such that cable-laying operations cannot continue. To operate in such conditions, frequently updated and accurate weather forecasts are needed. This will require training and validating an ad-hoc model with regularly updated meteorological data for a few seasons in advance of the deployment operations, so that a reliable forecasting service can be available during deployment.

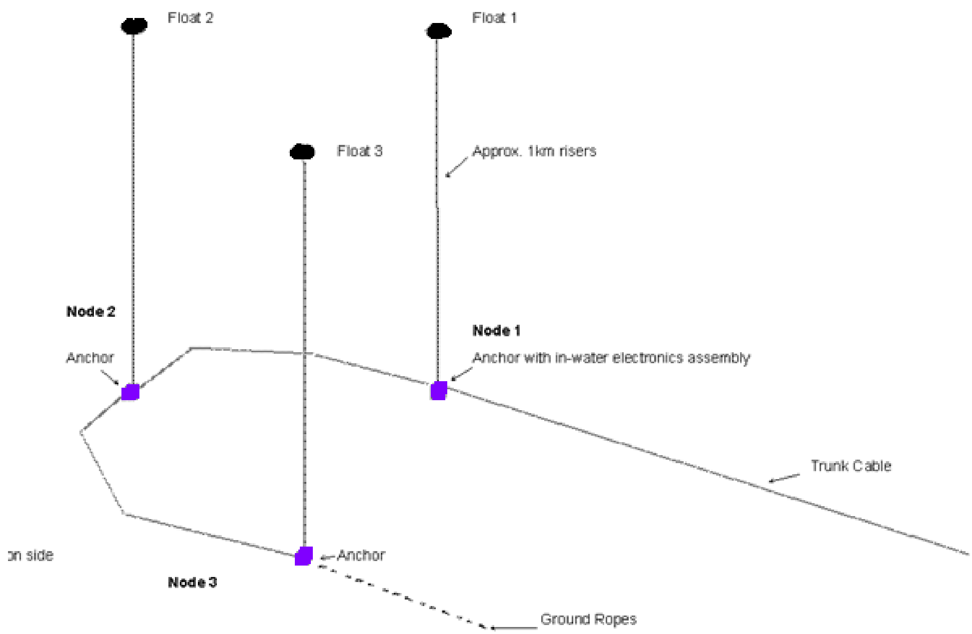
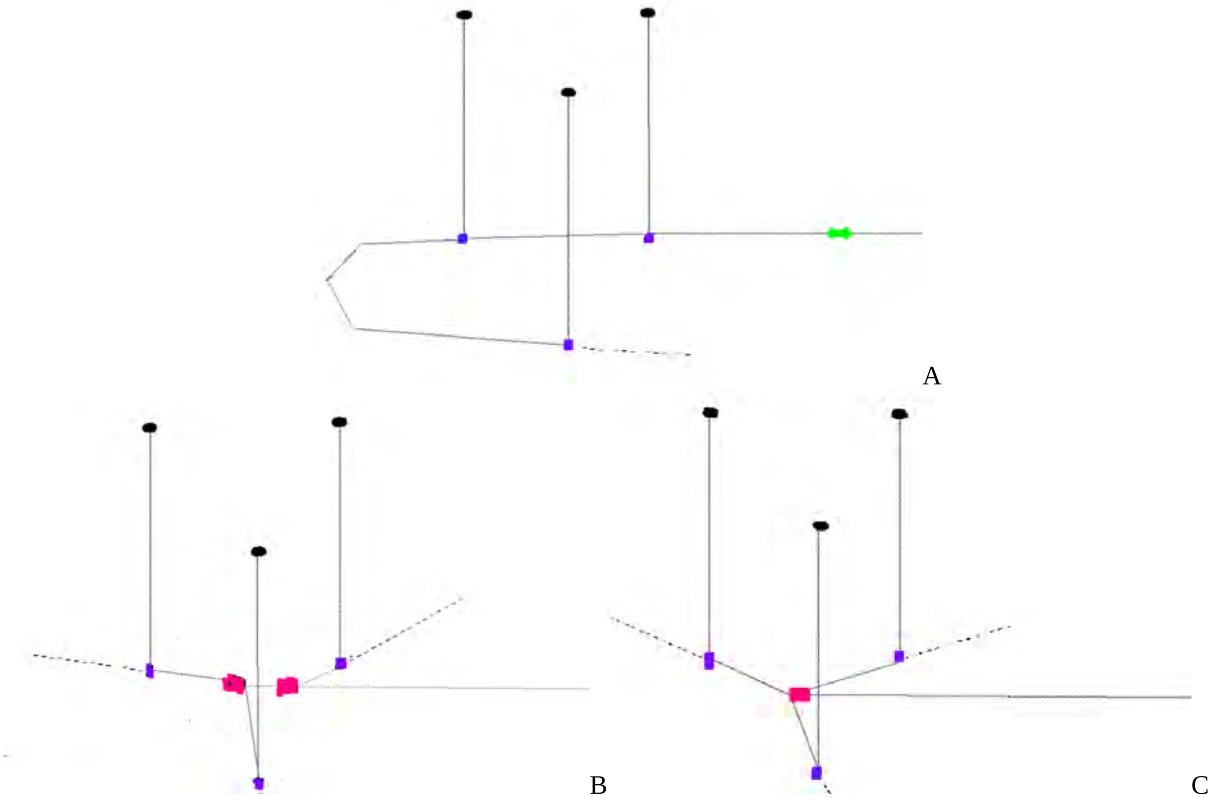


Figure 6. Linear station layout used at other IMS hydroacoustic stations. The three nodes are tied directly to the single trunk cable. (Figure from Mallin, 2012).

A linear layout was used for the current IMS hydrophone station triplets, where three hydrophone nodes are spliced directly onto the trunk cable. The cable is then laid with the three hydrophone nodes deployed as an equilateral triangle with a turn in the cable between each node (Figure 6). This avoids the need for connectors and branching units, but the design also requires that the deployment be done as one continuous process. Weather interruptions cannot be easily handled with this approach. The hydrophone node packages consist of an anchor package on the trunk cable, a riser cable for the hydrophone, the hydrophone, and a float. Once the packages are on the seabed, pyrotechnic fasteners are triggered to release the hydrophone so that the float can raise the hydrophone to the intended depth. The pyrotechnic fastener is also designed to corrode in seawater over some tens of hours to provide a backup release mechanism. This limits the amount of time that the hydrophone package can be in the water before it reaches its intended deployment position. If the hydrophone package is in the water for a longer period of time it would have to be repaired, refurbished, or replaced before redeployment to the intended location. Complete deployment of a trunk cable and its associated triplet would typically be expected to require an uninterrupted good (or reasonable) weather window of 36 hours.

Modular designs may offer a means for subdividing the installation tasks into a series of shorter tasks, for example by separating the laying of the trunk cable from the deployment of the hydrophone triplet. This could be done with the triplet connected into a single junction box, which would be connected to the main trunk cable (Figure 7A), or a configuration involving the use of one or more branching units (Figures 7B and 7C). All of these configurations require connectors between segments, which until recently had to be mated on deck before the system was deployed into the water (dry mating). The configurations using branching units are complex to lay, requiring highly accurate positioning and station keeping techniques.



- **Figure 7. Three alternate hydrophone layouts using a modular approach. A) Linear layout with triplet connected to trunk cable with connector (green). B) Layout utilizing two branching units (red). C) Layout using sinle branching unit. (Figures from [Mallin, 2012])**

The layout with the single junction box connection and the linear one where the trunk cable is continuous share the same difficulties for maintenance of the hydrophones: the entire triplet must be recovered and replaced as a single unit. The slack and loops in the cable between the hydrophone nodes makes damage of this cable segment likely during recovery as well. Dry-mateable connectors require that both the hydrophone unit needing repair and the branching unit to which it connects be brought to the surface.

More recently, wet-mateable connectors have come into use. These allow the connections to be made underwater with a remotely operated vehicle (ROV). This would help avoid many of the complex surface-handling activities required for the configurations involving dry-mateable connectors, as elements could be separately deployed to their mooring positions on the seafloor and then subsequently connected using an ROV. Similarly, in cases where maintenance is needed on individual hydrophone nodes or branching units, an ROV could be used to disconnect the unit underwater allowing that single item to be recovered, repaired/replaced, and reset. The ROV would then be used to reconnect the elements.

The complexities of ROV operation should not be underestimated, as these require specialized operators and deployment and recovery are limited by sea state. This could cause substantial delays and problems if the sea state rises to a level where the ROV cannot be recovered in time and the ship cannot hold station. Further issues which

need to be addressed regarding wet-mateable connectors are power limitations for the connectors, which may require a dry-mateable connector at the junction of the branching unit with the trunk cable towards the shore, and maintenance issues with the underwater connectible junction boxes, which are more complex and in some designs contain components which require periodic servicing.

In general, modular designs can improve the resilience of the system by eliminating single-points-of-failure that compromise the functionality of other components. Breaking deployment efforts into sub-tasks makes it possible to mitigate weather risks and deployment related equipment damage risks.

CONCLUSIONS AND RECOMMENDATIONS

Installing a hydrophone station at Crozet Island is a very significant and challenging undertaking. While the location has important advantages for the capabilities of the IMS network, the remoteness of the location and the environmental challenges will require careful consideration to design a station for reliable deployment and sustainable operation. Planning and preparation will be key to a successful installation. Preliminary bathymetric, oceanographic and acoustic studies are instrumental in this sense. Thorough testing of the equipment to be installed before integration and deployment is essential. Whatever final design configuration is implemented, the vessel used must be suitable for the weather conditions which may be encountered during the deployment operations. Further research of modular design solutions and state-of-the-art subcomponents is warranted as these could significantly decrease maintenance and sustainability challenges for HA04 and other future cabled ocean systems.

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